

JAP20 Rec'd PCT/PTO 26 MAY 2006

Description

Organic electroluminescent element

- 5 The present invention describes a novel design principle for organic electroluminescent elements and the use thereof in displays based thereon.

In a number of different applications which can be ascribed to the electronics industry in the broadest sense, the use of organic semiconductors as functional materials has been reality 10 for some time or is expected in the near future. Thus, light-sensitive organic materials (for example phthalocyanines) and organic charge-transport materials (generally hole transporters based on triarylamine) have already been used for many years in photocopiers. The use of semiconducting organic compounds which are capable of the emission of light in the visible spectral region is just at the beginning of the market introduction, for example in 15 organic electroluminescent devices. The individual components thereof, the organic light-emitting diodes (OLEDs), have a very broad range of applications as:

1. white or coloured backlighting for monochromatic or multicoloured display elements (such as, for example, in calculators, mobile telephones, etc.),
2. large-area displays (such as, for example, traffic signs, placards, etc.),
3. illumination elements in all colours and shapes,
4. monochromatic or full-colour passive matrix displays for portable applications (such as, for example, mobile telephones, PDAs, camcorders, etc.),
5. full-colour, large-area, high-resolution active matrix displays for a very wide variety of applications (such as, for example, mobile telephones, PDAs, laptops, TVs, etc.).

25 For devices containing relatively simple OLEDs, the market introduction has already taken place, as confirmed by the car radios from Pioneer, the mobile telephones from Pioneer and SNMD or a digital camera from Kodak with an "organic display". Further products of this type are just about to be introduced. Nevertheless, significant improvements are still necessary here in order to make these displays a true competitor to the liquid-crystal displays 30 (LCDs) which currently dominate the market, or to surpass them.

A development in this respect which has emerged in recent years is the use of organo-metallic complexes which exhibit phosphorescence instead of fluorescence (M. A. Baldo, S. Lamansky, P. E. Burrows, M. E. Thompson, S. R. Forrest, *Appl. Phys. Lett.*, 1999, 75, 4-6).

35 For quantum-mechanical reasons, an up to four-fold quantum, energy and power efficiency

is possible using organometallic compounds. Whether this new development will become established is on the one hand highly dependent on whether corresponding device compositions are found which are also able to implement these advantages (triplet emission = phosphorescence compared with singlet emission = fluorescence) in the OLEDs. It is not only the development of the organometallic compounds themselves that is of importance here, but also, in particular, of further materials specifically required for this purpose, such as, for example, so-called matrix or also hole-blocking materials. Essential conditions that may be mentioned here for practical use are, in particular, a long operating lifetime, high stability to thermal stresses and a low use and operating voltage together with high power efficiency, in order to facilitate mobile applications.

An organic electroluminescent device usually consists of a plurality of layers which are applied to one another by means of vacuum methods or various printing methods. For phosphorescent organic electroluminescent devices, these layers are in detail:

- 15 1. A support plate = substrate (usually glass or plastic sheet).
2. A transparent anode (usually indium-tin oxide, ITO).
3. A hole-injection layer (HIL): for example based on copper phthalocyanine (CuPc) or conductive polymers, such as polyaniline (PANI) or polythiophene derivatives (such as PEDOT).
- 20 4. One or more hole-transport layers (HTL): usually based on triarylamine derivatives, for example 4,4',4''-tris(N-1-naphthyl)-N-phenylamino)triphenylamine (NaphDATA) as the first layer and N,N'-di(naphth-1-yl)-N,N'-diphenylbenzidine (NPB) as the second hole-transport layer.
- 25 5. One or more emission layers (EML): usually comprising matrix materials, such as, for example, 4,4'-bis(carbazol-9-yl)biphenyl (CBP), doped with phosphorescent dyes, for example tris(phenylpyridyl)iridium (Ir(PPy)₃) or tris(2-benzothienylpyridyl)iridium (Ir(BTP)₃). However, the emission layer may also consist of polymers, mixtures of polymers, mixtures of polymers and low-molecular-weight compounds or mixtures of various low-molecular-weight compounds.
- 30 6. A hole-blocking layer (HBL): usually comprising BCP (2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline = bathocuproin) or bis(2-methyl-8-quinolinolato)-4-(phenylphenolato)-aluminium(III) (BAIq).
7. An electron-transport layer (ETL): usually based on aluminium tris-8-hydroxyquinolate (AlQ₃).

8. An electron-injection layer (EIL) (also known as insulator layer (ISL)): thin layer consisting of a material having a high dielectric constant, such as, for example, LiF, Li₂O, BaF₂, MgO, NaF.
9. A cathode: generally metals, metal combinations or metal alloys with a low work function, for example Ca, Ba, Cs, Mg, Al, In, Mg/Ag.

5 This device is appropriately (depending on the application) structured, provided with contacts and finally also hermetically sealed, since the lifetime of such devices is generally drastically shortened in the presence of water and/or air. The same also applies to so-called inverted structures, in which the light is coupled out of the cathode. In these inverted
10 OLEDs, the anode consists, for example, of Al/Ni/NiOx or Al/Pt/PtOx or other metal/metal oxide combinations which have a highest occupied molecular orbital (HOMO) having an energy of greater than 5 eV. The cathode here consists of the same materials described in points 9 and 10, with the difference that the metal is very thin and thus transparent. The layer thickness is less than 50 nm, better less than 30 nm, still better less than 10 nm. A
15 further transparent material, for example ITO (indium-tin oxide), IZO (indium-zinc oxide), etc., can also be applied to this transparent cathode.

Depending on the device structure, a plurality of these layers may also coincide or each of these layers does not necessarily have to be present.

20 However, there are still considerable problems which require urgent improvement:

1. For example, in particular, the operating lifetime of OLEDs is still short, meaning that it has hitherto only been possible to implement simple applications commercially.
2. This relatively short lifetime gives rise to a secondary problem: especially for full-colour
25 applications ("full-colour displays"), i.e. displays which have no segmentation, but instead are able to display all colours over the entire area, it is particularly unfavourable if the individual colours age at different rates here, as is currently the case. This results in the white point shifting significantly before the end of the above-mentioned lifetime (which is generally defined by a drop to 50% of the initial brightness), i.e. the colour
30 fidelity of the representation in the display becomes very poor. In order to circumvent this some display manufacturers define the lifetime as 70% or 90% lifetime (i.e. drop in the initial brightness to 70% or to 90% of the initial value). However, this results in the lifetime becoming even shorter.

3. Although the efficiencies, in particular the power efficiency (measured in lm/W), of OLEDs are acceptable, improvements are still also desired here – especially for portable applications.
4. The colour coordinates of OLEDs are not good enough. In particular, the combination of good colour coordinates with high efficiency still has to be improved.
5. The ageing processes are generally accompanied by an increase in the voltage. This effect makes voltage-driven organic electroluminescent devices difficult or impossible. However, current-driven addressing is more complex and expensive in this very case.
6. Precisely in the case of efficient phosphorescent OLEDs, the requisite operating voltage 10 is quite high and therefore has to be reduced further in order to improve the power efficiency. This is of major importance, especially for portable applications.
7. The requisite operating current has likewise been reduced in recent years, but still has to be reduced further in order to improve the power efficiency. This is particularly important especially for portable applications.
- 15 8. The structure of the OLEDs is complex and expensive due to the multiplicity of organic layers.

The above-mentioned problems make improvements in the production of OLEDs necessary. In particular, improvements in the area of the matrix and hole-blocking materials are of 20 major importance here.

In phosphorescent OLEDs, a hole-blocking layer (HBL) is usually used after the emitter layer in order to increase the efficiency and lifetime. These device structures are usually optimised in accordance with the criterion of maximum efficiency. BCP (bathocuproin) is frequently used here as hole-blocking material (HBM), with which very good efficiencies are achieved (D. F. O'Brien *et al.*, *Appl. Phys. Lett.* **1999**, *74*, 442), but with the major disadvantage that the lifetime of the OLEDs comprising BCP is greatly restricted. T. Tsutsui *et al.* (*Japanese J. Appl. Phys.* **1999**, *38*, L1502) indicate, as the reason for the restricted lifetime, the low stability of BCP, meaning that these devices cannot be used in high-quality display applications. A further hole-blocking material is bis(2-methyl-8-hydroxyquinolato)(4-phenyl-phenolato)aluminium(III) (BAIq). It has enabled the stability and the lifetime of the devices to be significantly improved, but with the disadvantage that the quantum efficiency of the devices comprising BAIq is significantly (about 40%) lower than with BCP (T. Watanabe *et al.*, *Proc. SPIE* **2001**, *4105*, 175). Kwong *et al.* (*Appl. Phys. Lett.* **2002**, *81*, 162) thus achieved lifetimes of 10,000 h with tris(phenylpyridyl)iridium(III). However, this device

exhibited an efficiency of only 19 cd/A, which is well behind the prior art. Thus, although good lifetimes are possible with BAIq, it is overall not a satisfactory hole-blocking material since the efficiency achieved is too low.

- 5 As is also evident from the above-described structure of a phosphorescent OLED, this is very complex since a large number of layers, which in turn consist of many different materials, have to be applied one after the other, which makes the production process of commercial OLEDs very complicated and complex.
- 10 It is clearly evident from this description that the hole-blocking materials (HBMs) BCP and BAIq in accordance with the prior art used to date result in unsatisfactory side effects. There thus continues to be a demand for hole-blocking materials which result in good efficiencies, but at the same time also in long lifetimes, in OLEDs. Surprisingly, it has now been found that OLEDs which comprise certain classes of material – indicated below – as hole-blocking materials have significant improvements over the prior art. Using these classes of material, it is possible simultaneously to obtain high efficiencies and good lifetimes, which is not possible using materials in accordance with the prior art. In addition, it has been found that a separate electron-transport layer does not necessarily have to be used with the novel hole-blocking materials, which represents a technological advantage, and that consequently the 15 operating voltages can additionally be significantly reduced, which corresponds to higher power efficiency.
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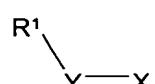
The invention relates to an organic electroluminescent device comprising anode, cathode and at least one emission layer comprising at least one matrix material A which is doped 25 with at least one phosphorescent emitter, and at least one hole-blocking layer comprising at least one hole-blocking material B, characterised in that the hole-blocking material B contains at least one chemical structural unit of the formula Y=X, where X has at least one non-bonding electron pair and where the radical X stands for NR, O, S, Se or Te, and R stands for an organic radical having 1 to 22 carbon atoms or for OH, OR, NH₂, NHR⁶ or N(R⁶)₂, 30 where R⁶ = H or an organic radical having 1 to 20 C atoms, and where the radical Y stands for C, P, As, Sb, Bi, S, Se or Te, with the proviso that the matrix material A is not identical with the hole-blocking material B.

35 Although evident from the above, it should again explicitly be pointed out here that A and B may contain the same structural unit Y=X, but are otherwise different.

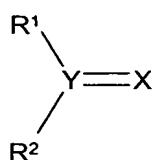
The symbol "≡" used above and below stands for a double bond in the sense of the Lewis notation.

- 5 Preference is given to an organic electroluminescent device which is characterised in that it comprises a hole-blocking material B conforming to the formulae (1) to (4) according to scheme 1

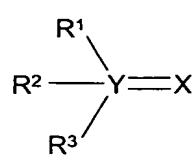
Scheme 1



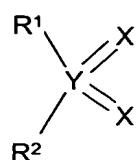
Formula (1)



Formula (2)



Formula (3)



Formula (4)

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where the symbols used have the following meaning:

Y is, identically or differently on each occurrence, C in the formula (2) and P, As, Sb or Bi in the formulae (1) and (3) and S, Se or Te in the formulae (2) and (4);

15 X is on each occurrence, identically or differently, NR⁴, O, S, Se or Te;

R¹, R², R³ is on each occurrence, identically or differently, H, F, CN, N(R⁴)₂, a straight-chain, branched or cyclic alkyl, alkoxy or thioalkoxy group having 1 to 40 C atoms, which may be substituted by R⁵ or also unsubstituted, in which one or more non-adjacent CH₂ groups may be replaced by -R⁶C=CR⁶-, -C≡C-, Si(R⁶)₂, Ge(R⁶)₂, Sn(R⁶)₂, C=O, C=S, C=Se, C=NR⁶, -O-, -S-, -NR⁶- or -CONR⁶- and in which one or more H atoms may be replaced by F, Cl, Br, I, CN or NO₂, or an aromatic or heteroaromatic ring system or an aryloxy or heteroaryloxy group having 1 to 40 aromatic C atoms, which may be substituted by one or more radicals R⁵; a plurality of substituents R¹, R² and/or R³ here may form a mono- or polycyclic, aliphatic or aromatic ring system with one another; or an aromatic or heteroaromatic ring system bonded via a divalent group -Z-, or an aryloxy or heteroaryloxy group, each having 1 to 40 aromatic C atoms, in which one or more H atoms may be replaced by F, Cl, Br or I or which may be substituted by one or more non-aromatic radicals R⁴, where a plurality of substituents R⁴ may define a further mono- or polycyclic, aliphatic or aromatic ring system;

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5 R⁴ is on each occurrence, identically or differently, a straight-chain, branched or cyclic alkyl or alkoxy chain having 1 to 22 C atoms, in which, in addition, one or more non-adjacent C atoms may be replaced by -R⁶C=CR⁶-, -C≡C-, Si(R⁶)₂, Ge(R⁶)₂, Sn(R⁶)₂, -NR⁶-, -O-, -S-, -CO-O- or -O-CO-O- and in which one or more H atoms may be replaced by fluorine, an aryl, heteroaryl or aryloxy group having 1 to 40 C atoms, which may also be substituted by one or more radicals R⁶, or OH or N(R⁵)₂;

10 R⁵ is on each occurrence, identically or differently, R⁴ or CN, B(R⁶)₂ or Si(R⁶)₃;

15 R⁶ is on each occurrence, identically or differently, H or an aliphatic or aromatic hydrocarbon radical having 1 to 20 C atoms;

20 Z is a straight-chain, branched or cyclic, preferably conjugated radical having 1 to 40 C atoms, which is preferably conjugated with the two other substituents, where the number of atoms of Z which link the group of the formula (1) and the aromatic radical is preferably an even number, where one or more non-adjacent C atoms may be replaced by -O-, -S- or -NR¹- and one or more C atoms may be substituted by a radical R¹ or halogen;

25 and with the proviso that the molecular weight of the hole-blocking material B is greater than 150 g/mol.

30 For the purposes of this invention, an aromatic or heteroaromatic ring system is taken to mean a system which does not necessarily comprise only aromatic or heteroaromatic groups, but instead in which a plurality of aromatic or heteroaromatic groups may also be interrupted by a short, non-aromatic unit, such as, for example, an sp³-hybridised C, N or O atom. Thus, for example, systems such as 9,9'-spirobifluorene, 9,9-diarylfluorene, triarylamine, diaryl ether, etc., should also be taken to mean aromatic ring systems for the purposes of this application.

Very particular preference is given to an organic electroluminescent device which is characterised in that Y = C, P or S, and X = O.

35 It may also be preferred for the hole-blocking material B to contain more than one unit Y=X or more than one unit of the formulae (1) to (4).

The hole-blocking layer preferably comprises at least 50% of the hole-blocking material B, particularly preferably at least 80%, very particularly preferably consists only of the hole-blocking material B.

- 5 Preferred hole-blocking materials B have proven to be compounds which carry an aromatic or heteroaromatic group bonded directly to Y in at least one of the radicals R¹, R² and R³. Particular preference is given to compounds which carry aromatic or heteroaromatic groups bonded directly to Y in all the radicals R¹, R² and R³ present.
- 10 Particularly suitable hole-blocking materials B have proven to be compounds which do not have a planar structure. Corresponding substituents on the structural unit of the form Y=X may ensure a deviation of the overall structure from planarity. This is the case, in particular, if at least one of the substituents R¹, R², R³ and/or R⁴ contains at least one sp³-hybridised carbon, silicon, germanium and/or nitrogen atom which consequently has approximately 15 tetrahedral or, in the case of nitrogen, pyramidal bonding geometry.
- In order to achieve a significant deviation from planarity, it is preferred for at least one of the sp³-hybridised atoms to be a secondary, tertiary or quaternary atom, particularly preferably a tertiary or quaternary atom, in the case of carbon, silicon or germanium very particularly preferably a quaternary atom.
- 20 A secondary, tertiary or quaternary atom is taken to mean an atom having two, three or four substituents other than hydrogen.
- Preference is given to compounds which contain a 9,9'-spirobifluorene derivative, preferably linked via the 2- and/or 2,7- and/or 2,2'- and/or 2,2',7,7'-position, a 9,9-25 disubstituted fluorene derivative, preferably linked via the 2- and/or 2,7-position, a 6,6- and/or 12,12-di- or tetrasubstituted cis- or trans-indenofluorene derivative, a triptycene derivative, preferably linked via the 9- and/or 10-position, a dihydrophenanthrene derivative, preferably linked via the 2- and/or 2,7-position, a hexaarylbenzene derivative, preferably linked via the p-position on the aromatic ring(s), or a tetraarylmethane derivative, preferably linked via the p-position on the aromatic ring(s), in at least one of the radicals R.
- 30 Particular preference is given to compounds which contain a 9,9'-spirobifluorene derivative or a 9,9-disubstituted fluorene derivative, very particularly preferably a 9,9'-spirobifluorene derivative, in at least one of the radicals R¹, R², R³ or R⁴.

The present invention furthermore relates to the use of compounds of the chemical structural unit of the formula Y=X, where X has at least one non-bonding electron pair and where the radical X stands for NR, O, S, Se or Te and R stands for an organic radical having 1 to 22 carbon atoms or for OH, OR, NH₂, NHR⁶ or N(R⁶)₂, where R⁶ = H or an organic radical having 1 to 20 C atoms, and where the radical Y stands for C, P, As, Sb, Bi, S, Se or Te, as hole-blocking material in an organic light-emitting diode.

Preference is given to an organic electroluminescent device which is characterised in that the matrix materials A are selected from the classes of carbazoles, for example in accordance with WO 00/057676, EP 01202358 and WO 02/074015, ketones and imines, for example in accordance with WO 04/093207, phosphine oxides, phosphine sulfides, phosphine selenides, phosphazenes, sulfones, sulfoxides, for example in accordance with DE 10330761.3, silanes, polypodal metal complexes, for example in accordance with WO 04/081017, and oligophenylenes based on spirobifluorenes, for example in accordance with EP 676461 and WO 99/40051. Particular preference is given to ketones, phosphine oxides and sulfoxides.

However, this selection is not crucial for the subject-matter of the invention. For example, further known materials, such as derivatives of carbazole, can also be used.

The OLED described above may also comprise further layers, such as, for example, a hole-injection layer, hole-transport layer, electron-injection layer and/or electron-transport layer. However, it should be pointed out that all these layers do not necessarily have to be present. Thus, it has been found that OLEDs according to the invention which comprise a hole-blocking layer consisting of a hole-blocking material B continue to give comparably good efficiencies and lifetimes at lower operating voltage if no electron-injection and electron-transport layers are used.

Preference is therefore given to organic electroluminescent devices in which the hole-blocking layer is directly adjacent to the electron-injection layer or cathode.

Preference is furthermore given to an organic electroluminescent device which is characterised in that the phosphorescent emitter present is a compound which contains at least one atom having an atomic number of greater than 36 and less than 84.

Particular preference is given to an organic electroluminescent device which is characterised in that the phosphorescent emitter contains at least one element having an atomic number of greater than 56 and less than 80, very particularly preferably molybdenum, tungsten, rhenium, ruthenium, osmium, rhodium, iridium, palladium, platinum, silver, gold and/or europium, for example in accordance with WO 98/01011, US 02/0034656, US 03/0022019, WO 00/70655, WO 01/41512, WO 02/02714, WO 02/15645, EP 1191613, EP 1191612, EP 1191614, WO 03/040257, WO 03/084972 and WO 04/026886.

Preference is furthermore given to an organic electroluminescent device which is characterised in that the glass transition temperature T_g of the hole-blocking material B is greater than 100°C, preferably greater than 120°C, very particularly preferably greater than 140°C.

Preference is furthermore given to an organic electroluminescent device which is characterised in that one or more layers are coated by a sublimation process, in which the low-molecular-weight materials are vapour-deposited in vacuum sublimation units at a pressure below 10^{-5} mbar, preferably below 10^{-6} mbar, particularly preferably below 10^{-7} mbar.

Preference is likewise given to an organic electroluminescent device which is characterised in that one or more layers are coated by the OVPD (organic vapour phase deposition) process or with the aid of carrier-gas sublimation, which are known to the person skilled in the art and in which the low-molecular-weight materials are applied at a pressure between 10^{-5} mbar and 1 bar.

Preference is furthermore given to an organic electroluminescent device which is characterised in that one or more layers are coated by any desired printing process, such as, for example, flexographic printing or offset printing, particularly preferably LITI (light induced thermal imaging, thermal transfer printing) or ink-jet printing.

The emitting devices described above have the following surprising advantages over the prior art:

- 30 1. The efficiency of corresponding devices is increased compared with systems which do not follow the design according to the invention.
2. The stability and thus the lifetime of corresponding devices is increased compared with systems which do not follow the design according to the invention.

3. The operating voltages are significantly reduced and consequently the power efficiency is increased. This applies, in particular, if a separate electron-transport layer is not used.
 4. The layer structure is simpler since it is possible to use at least one organic layer, namely the electron-transport layer, less, which results in lower production complexity.
- 5 This is a considerable advantage in the production process since in the conventional production process, a separate vapour-deposition unit is generally used for each organic layer, and consequently at least one such unit is thus saved or omitted entirely.

The present application text and also the further examples below are directed only to
10 organic light-emitting diodes and the corresponding displays. In spite of this restriction of the description, it is possible for the person skilled in the art, without further inventive step, also to use the corresponding design according to the invention for other, related devices, for example for organic solar cells (O-SCs), organic field-effect transistors (O-FETs) or also organic laser diodes (O-lasers), to mention but a few further applications. The present
15 invention likewise relates to these.

Examples:

Production and characterisation of organic electroluminescent devices which correspond to the structure according to the invention.

20 The OLEDs were produced by the general process outlined below. This was adapted in individual cases to the particular circumstances (for example layer-thickness variation in order to achieve optimum efficiency or colour). Electroluminescent devices according to the invention can be produced as described, for example, in DE10330761.3.

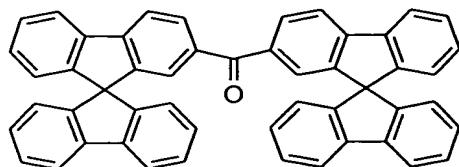
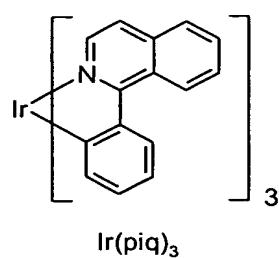
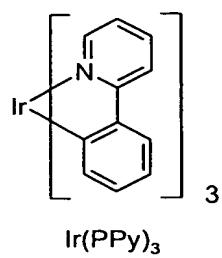
25 The results for various OLEDs are presented in the following examples. The basic structure, such as the materials and layer thicknesses used, apart from the EML and HBL, were identical for better comparability. Emitting OLEDs having the following structure were produced analogously to the above-mentioned general process:

PEDOT (HIL)	60 nm (spin-coated from water; PEDOT purchased from H.C. Starck; poly-[3,4-ethylenedioxy-2,5-thiophene])
NaphDATA (HTM)	20 nm (vapour-deposited; NaphDATA purchased from SynTec; 4,4',4''-tris(N-1-naphthyl-N-phenylamino)triphenylamine)
S-TAD (HTM)	20 nm (vapour-deposited; S-TAD prepared as described in WO 99/12888; 2,2',7,7'-tetrakis(diphenylamino)spirobifluorene)

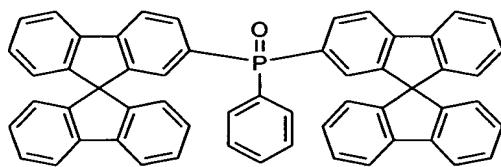
	Emitter layer (EML)	30 nm (precise structure: see examples in Table 1)
	Hole-blocking layer (HBL)	10 nm (see examples in Table 1)
	AlQ ₃ (ETL)	20 nm (vapour-deposited: AlQ ₃ purchased from SynTec; tris(quinolinato)aluminium(III)); not used in all examples
5	Ba/Al (cathode)	3 nm Ba, 150 nm Al on top

These as yet unoptimised OLEDs were characterised by standard methods; for this purpose, the electroluminescence spectra, the efficiency (measured in cd/A), the power efficiency (measured in lm/W) as a function of the brightness, calculated from current/voltage/brightness characteristic lines (IUL characteristic lines), and the lifetime were determined. The lifetime is taken to mean the time after which the initial brightness of the OLED has dropped to half at a constant current density of 10 mA/cm².

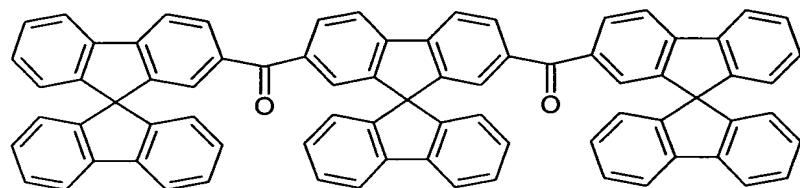
Table 1 shows the results for various examples. The composition of the EML and HBL, including the corresponding layer thicknesses, is shown. The doped phosphorescent EMLs comprise as matrix material **A1** the compound bis(9,9'-spirobifluoren-2-yl) ketone (synthesised as described in WO 04/093207), as matrix material **A2** the compound bis(9,9'-spirobifluoren-2-yl)phenylphosphine oxide (synthesised as described in DE 10330761.3), as matrix material **A3** 2,7-bis(2-spiro-9,9'-bifluorenylcarbonyl)spiro-9,9'-bifluorene (synthesised as described in WO 04/093207) or as matrix material **A4** CBP (4,4'-bis(N-carbazolyl)-biphenyl), as emitter the compounds Ir(PPy)₃ or Ir(piq)₃ (both synthesised as described in WO 02/060910), and as hole-blocking material **B1** the compound bis(9,9'-spirobifluoren-2-yl) ketone, as hole-blocking material **B2** the compound bis(9,9'-spirobifluoren-2-yl)phenylphosphine oxide, or as hole-blocking material **B3** the compound 2,7-bis(2-spiro-9,9'-bifluorenylcarbonyl)spiro-9,9'-bifluorene. OLEDs which comprise B-Alq as hole-blocking material serve as comparative examples. The figure below shows the corresponding structural formulae of the substances used.



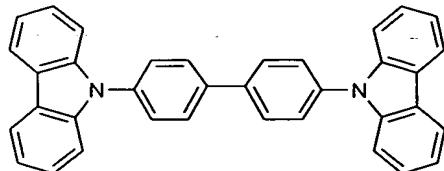
Bis(9,9'-spirobifluoren-2-yl) ketone
Matrix material A1
Hole-blocking material B1



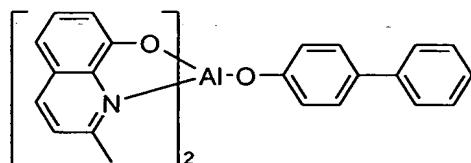
Bis(9,9'-spirobifluoren-2-yl)phenylphosphine oxide
Matrix material A2
Hole-blocking material B2



2,7-Bis(2-spiro-9,9'-spirobifluorenylcarbonyl)spiro-9,9'-bifluorene
Matrix material A3
Hole-blocking material B3



CBP
Matrix material A4



BAiq

Table 1:

Experiment	EML	HBL	ETL	Max. efficiency (cd/A)	Max. power efficiency (lm/W)	Voltage (V) at 100 cd/m ²	Lifetime (h) at 10 mA/cm ²
Example 1a	A2:10% IrPPy	B1	AlQ ₃	29.1	16.5	4.7	630
Example 1b (comparison)	A2:10% IrPPy	BAIq	AlQ ₃	25.2	14.8	5.7	510
Example 2 a	A2:10% IrPPy	B1	—	30.2	19.1	3.5	710
Example 2 b (comparison)	A2:10% IrPPy	BAIq	—	24.8	14.7	5.2	240
Example 3	A3:10% Ir(piq) ₃	B1	AlQ ₃	7.3	7.1	4.9	about 23000 (extrapolated)
Example 4a	A3:10% Ir(piq) ₃	B1	—	7.5	8.1	4.5	about 18000 (extrapolated)
Example 4b (comparison)	A3:10% Ir(piq) ₃	BAIq	—	6.6	5.4	5.5	about 2600 (extrapolated)
Example 5	A1:10% IrPPy	B2	AlQ ₃	34.0	26.9	4.1	590
Example 6	A1:10% IrPPy	B2	—	32.7	27.7	3.5	490
Example 7 a	CBP:10% IrPPy	B2	AlQ ₃	29.7	17.2	4.5	650

Example 7 b (comparison)	CBP:10% IrPPy	BAlq	A1Q₃	18.3	8.5	5.1	250
Example 8 a	CBP:10% IrPPy	B2	—	27.2	15.9	5.1	330
Example 8 b (comparison)	CBP:10% IrPPy	BAlq	—	16.5	8.8	5.3	180
Example 9	A1:10% IrPPy	B3	A1Q₃	30.5	25.0	4.8	450
Example 10	A1:10% Ir(piq)₃	B3	A1Q₃	6.5	6.4	5.1	about 25000 (extrapolated)
Example 11 a	A1:10% Ir(piq)₃	B3	—	7.5	8.1	4.5	about 20000 (extrapolated)
Example 11 b (comparison)	A1:10% Ir(piq)₃	BAlq	—	6.1	5.2	5.6	about 5000 (extrapolated)

The OLEDs exhibit green emission from the dopant Ir(PPy)₃ and red emission from the dopant Ir(piq)₃.

In all examples, a significant improvement in the efficiency and lifetime with reduced operating voltage is evident compared with devices in accordance with the prior art which comprise B-Alq as hole-blocking material.

A similar trend is also evident if a separate ETL is not used. In the OLEDs in accordance with the prior art, the photometric efficiency decreases and the lifetime is significantly shortened compared with OLEDs comprising an ETL. This is not the case in the OLEDs manufactured in accordance with the novel design principle, where, in particular, the voltages drop, causing an improvement in the power efficiency.

In summary, it can be stated that OLEDs manufactured in accordance with the novel design principle have higher efficiency at lower voltage and longer lifetime, as can easily be seen from Table 1.